Proceedings of Business and Economic Studies, 2026, Volume 9, Issue 6
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Resilience Evaluation and Improvement Strategies of Dalian Port Incorporating the Dimension of Low-Altitude Economy

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Abstract: This paper takes Dalian Port as a starting point to explore evaluation ideas and optimization plans for port resilience. Based on a review of existing literature and on-site investigations, an evaluation system is constructed from four perspectives: infrastructure, operation and management, low-altitude economy, and sustainable development. The Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methods are employed to comprehensively assess the overall resilience level of Dalian Port. The calculation results indicate that Dalian Port has significant advantages in infrastructure, stable operation and management, and sustainable development, but lags relatively behind in the development of the low-altitude economy. Based on the current issues, specific suggestions are proposed in the paper: continuously strengthening infrastructure construction, improving operation and management mechanisms, promoting the deep integration of the low-altitude economy with the port, and continuously implementing green development plans, etc. The conclusions drawn from this analysis can provide certain reference value for Dalian Port and other ports to enhance their resilience through the low-altitude economy.

Keywords: Low-altitude economy; Dalian Port; Port resilience; Analytic Hierarchy Process; Fuzzy Comprehensive Evaluation

Online publication: July 15, 2026

1. Introduction

At present, the process of globalization, coupled with the impact of climate change, has led to a continuous increase in security risks and operational challenges faced by ports, which serve as core nodes for trade circulation and material transfer. The comprehensive ability of ports to withstand risks and resume operations has now become a key consideration in industry management. The development of the low-altitude economy has injected new impetus into the establishment of a three-dimensional logistics network and the enhancement of operational flexibility for ports, becoming an important support for building highly resilient ports. Taking

Dalian Port as an example, this paper incorporates the low-altitude economy into the resilience evaluation framework and proposes corresponding improvement paths to help ports strengthen their emergency response and environmental adaptability, while also providing a theoretical basis and practical references for the improvement of their operation and management.

Today, with abnormal global climate, volatile regional situations, and continuous technological innovations, Dalian Port, a comprehensive hub located in Northeast China, serves as a core carrier for regional economic and foreign trade development, while also facing increasingly severe operational challenges and security tests [1]. The rise of the low-altitude industry has opened up a new direction for strengthening the port's risk resistance capabilities. Based on this, this paper conducts research on the resilience evaluation and optimization of Dalian Port in conjunction with the low-altitude economy, which holds both theoretical value and practical significance [2]. This paper combines qualitative and quantitative analysis methods to analyze the comprehensive resilience of ports from dimensions such as infrastructure, operation and management, low-altitude economy, and sustainable development, clarifies the internal logic of how low-altitude industries empower port risk prevention and dynamic adaptation, and ultimately provides scientific planning ideas and practical solutions for port quality improvement and upgrading, as well as the coordinated development with the low-altitude economy.

2. Resilience evaluation of Dalian Port

This paper conducts a comprehensive resilience evaluation of Dalian Port, constructing an evaluation system from four major directions: infrastructure, operation and management, low-altitude economy, and sustainable development [3]. Among them, infrastructure focuses on examining the port's hardware conditions and its disaster resistance capabilities; operation and management emphasize operational efficiency, informatization level, and control capabilities; the low-altitude economy focuses on the application of drones, low-altitude aircraft, etc., in three-dimensional transportation; sustainable development measures environmental performance, social responsibility, urban-port coordination, and long-term development potential.

This study employs the Analytic Hierarchy Process (AHP) to determine the weights of each indicator and uses the Fuzzy Comprehensive Evaluation (FCE) method to complete the quantitative evaluation of Dalian Port's resilience [4]. The AHP is a classic multi-objective decision-making tool that can effectively handle complex analytical scenarios; the FCE method, based on fuzzy mathematics, can properly resolve various fuzzy and uncertain evaluation problems [5].

3. Evaluation process

3.1. Determining indicator weights using the analytic hierarchy process

3.1.1. Establishing a hierarchical structure model

Decompose the problem into an objective layer and a criterion layer.

Objective layer: Determine the weights of evaluation indicators for Dalian Port;

Criterion layer: Infrastructure (C1), Operation and Management (C2), Low-Altitude Economy (C3), Sustainable Development (C4).

3.1.2. Constructing a judgment matrix

Determine the relative importance of each criterion through pairwise comparisons, using a 1-9 scale method in this process, where 1 indicates equal importance, and 9 indicates extreme importance. After evaluation by port experts, the judgment matrix for the criterion layer is obtained as shown in **Table 1**.

Table 1. Judgment matrix for the criterion layer

	C1	C2	C3	C4
C1	1	3	6	7
C2	1/3	1	3	6
C3	1/6	1/3	1	3
C4	1/7	1/6	1/3	1

3.1.3. Calculating weights

(1) Calculate the sum of each column:

Sum of C1 column: $1 + 1/3 + 1/6 + 1/7 \approx 1.64$

Sum of C2 column: $3+1+1/3+1/6 \approx 4.50$

Sum of C3 column: $6 + 3 + 1 + 1/3 \approx 10.33$

Sum of C4 column: $7 + 6 + 3 + 1 = 17.00$

(2) Normalize the judgment matrix by dividing each element by its column sum. The normalized judgment matrix is shown in **Table 2**, and the calculation results are presented in **Table 3**.

Table 2. Normalization of the judgment matrix

	C1	C2	C3	C4
C1	1/1.64	3/4.50	6/10.33	7/17.00
C2	(1/3)/1.64	1/4.50	3/10.33	6/17.00
C3	(1/6)/1.64	(1/3)/4.50	1/10.33	3/17.00
C4	(1/7)/1.64	(1/6)/4.50	(1/3)/10.33	1/17.00

Table 3. Calculation results

	C_1	C_2	C_3	C_4
C_1	0.610	0.667	0.581	0.412
C_2	0.203	0.222	0.290	0.353
C_3	0.102	0.074	0.097	0.176
C_4	0.087	0.037	0.032	0.059

(3) By calculating the average value of each row, the weight vector can be obtained as follows W :

$$W_{C_1} = (0.610 + 0.667 + 0.581 + 0.412) / 4 \approx 0.568$$

$$W_{C_2} = (0.203 + 0.222 + 0.290 + 0.353) / 4 \approx 0.267$$

$$W_{C_3} = (0.102 + 0.074 + 0.097 + 0.176) / 4 \approx 0.112$$

$$W_{C_4} = (0.087 + 0.037 + 0.032 + 0.059) / 4 \approx 0.054$$

The weight vector is thus obtained $W = [0.568,\ 0.267,\ 0.112,\ 0.054]$.

3.1.4. Consistency check C_i

(1) Consistency Index (CI):

$C_i = (\lambda_{\max} - n) / (n - 1)$ Here, λ_{max} represents the maximum eigenvalue of the judgment matrix, and n is the order of the matrix, with n=4 in this case.

(2) Calculate λ_{max}

$$\begin{bmatrix} 1 & 3 & 6 & 7 \\ 1/3 & 1 & 3 & 6 \\ 1/6 & 1/3 & 1 & 3 \\ 1/7 & 1/6 & 1/3 & 1 \end{bmatrix} * \begin{bmatrix} 0.568 \\ 0.267 \\ 0.112 \\ 0.054 \end{bmatrix} \approx \begin{bmatrix} 2.419 \\ 1.116 \\ 0.458 \\ 0.217 \end{bmatrix}$$

$$\lambda_{max} = (2.419/0.568 + 1.116/0.267 + 0.458/0.112 + 0.217/0.054)/4 \approx 4.137$$

(3) Calculate the consistency index C_i.

$$C_i = (4.137 - 4) / (4 - 1) \approx 0.046$$

(4) Calculate the random consistency ratio C_R.

$C_R = C_i / R_i$, Where R_i represents the random consistency index (obtained by referring to a table; when n=4, R_i =0.90), therefore $C_R = 0.046 / 0.90 \approx 0.051$

(5) Assessing Consistency

Since $C_R < 1$, the consistency of the judgment matrix is therefore deemed acceptable.

3.1.5. Determining final weights

Based on the calculation results and consistency assessment, the weights of the respective indicators are determined as follows: Infrastructure (C1): 0.568, Operation and Management (C2): 0.267, Low-Altitude Economy (C3): 0.112, and Sustainable Development (C4): 0.054.

3.2. Evaluating port resilience level using fuzzy comprehensive evaluation method

After scientifically and objectively determining the weights corresponding to each indicator through the Analytic Hierarchy Process, the resilience level of Dalian Port is quantitatively evaluated using the Fuzzy Comprehensive Evaluation Method.

(1) Determining Evaluation Indicators and Weights

Evaluation Indicators: C1, C2, C3, C4

Weight Vector: $W = [0.568,\ 0.267,\ 0.112,\ 0.054]$

(2) Constructing the Evaluation Matrix

Based on expert evaluations, the scores assigned by experts to Dalian Port are shown in **Table 4**, with the scoring range being 0–10.

Table 4. Expert scoring sheet

Indicator	C1	C2	C3	C4
Score	9	8	7	8

(3) Standardization Processing

The scores are standardized to the range of [0,1], meaning that the scores undergo standardization processing, resulting in **Table 5**.

Table 5. Data after standardization processing

Indicator	C1	C2	C3	C4
Score	0.9	0.8	0.7	0.8

(4) Constructing the Fuzzy Evaluation Matrix Define the standardized data as the fuzzy evaluation matrix R.

$$R=\left[0.9,\ 0.8,\ 0.7,\ 0.8\right]$$

(5) Calculating the Comprehensive Evaluation Value

Perform weighted calculations using the weight vector W and the fuzzy evaluation matrix R:

$$Score=0.568*0.9+0.267*0.8+0.112*0.7+0.054*0.8=0.5112+0.2136+0.0784+0.0432=0.8464$$

(6) Result Analysis

The overall evaluation score of Dalian Port reaches 0.8464 (out of a maximum of 1), indicating a relatively good overall operational status. Breaking down the scores by dimension, infrastructure scores 0.9, showing a significant advantage among all dimensions; operation and management, as well as sustainable development, both score 0.8, indicating stable operational trends; the low-altitude economy scores 0.7, representing a key area for future improvement.

4. Pathways to enhance the resilience of Dalian Port

Based on the evaluation conclusions drawn from the analysis, this paper outlines several optimization strategies to strengthen the risk resilience of Dalian Port.

In terms of infrastructure, it is essential to continuously reinforce infrastructure construction, enhance the port's disaster resilience capabilities, optimize the overall layout planning of the port area, and accelerate the operational efficiency of cargo handling at the terminals. Regarding operation and management, it is crucial to improve the operation and management mechanisms, advance the process of digital and intelligent transformation, and leverage big data and intelligent technologies to streamline operational procedures and reduce resource consumption. In the realm of the low-altitude economy, it is advisable to expand the practical application scenarios of technologies, utilize drones for site inspections and cargo transfer operations, and promote their deep integration with the existing port system. For sustainable development, it is imperative to continuously implement green development plans, increase investment in environmental protection, expand the use of clean energy, reduce the ecological pollution pressure caused by daily operations, actively fulfill social obligations, and balance the collaborative relationships between the port, the city, and the community. By implementing these measures, Dalian Port will be able to comprehensively enhance its ability to withstand shocks and respond to risks, better cope with various risks, and achieve sustainable development.

5. Conclusion

This study establishes a framework for evaluating port resilience and conducts a systematic assessment of the actual resilience status of Dalian Port, while proposing corresponding optimization strategies. The research results indicate that Dalian Port has significant advantages in infrastructure, operation and management, and sustainable development, but there is room for improvement in the low-altitude economy. In the future, Dalian Port should focus on continuously strengthening infrastructure construction, improving operation and management mechanisms, promoting the deep integration of the low-altitude economy with the port, and continuously implementing green development plans to enhance its comprehensive resilience against risks.

This research not only provides theoretical support and practical implementation methods for Dalian Port to enhance its risk resilience but also offers references for similar ports to incorporate low-altitude industry elements into their resilience evaluation systems. Port resilience construction is a long-term endeavor that requires continuous follow-up adjustments and iterative optimizations. Subsequent research can delve into how new technologies such as drone operations, low-altitude communication and navigation, and automated inspections contribute to enhancing port risk resilience, and explore the integration pathways between the low-altitude industry and daily port operations to comprehensively strengthen the port's overall strength and enhance its ability to respond to various risks.

Funding

Research project by the China Logistics Society and the China Federation of Logistics & Purchasing titled "Research on Resilience Evaluation and Enhancement Strategies for Dalian Port from the Perspective of the Low-Altitude Economy" (Project Number: 2026CSLKT3-285)

Disclosure statement

The authors declare no conflict of interest.

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